AD-A094 454 NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA F/G 20/1

VERIFICATION OF THE ADIABATIC INVARIANT APPROXIMATION FOR COMPU--ETC(U)

SEP 80 J NORTHROP, R C SHOCKLEY, P G HANSEN

UNCLASSIFIED NOSC/TR-621 NL

1 OF 1

AD A094454

NOSC

END

DATE FILMED

2-81

DTIC

LEVEL II (12)

NOSC

NOSC TR 621

NOSC TR 621

AD A094454

Technical Report 621

VERIFICATION OF THE ADIABATIC INVARIANT APPROXIMATION FOR COMPUTING EFFECTIVE HORIZONTAL SOUND SPEEDS IN A RANGE-DEPENDENT ENVIRONMENT

J Northrop, RC Shockley, and PG Hansen

September 1980

Interim Report: April - September 1980

Prepared for
USAF Technical Applications Center

Approved for public release; distribution unlimited

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

SL GUILLE, CAPT, USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

This work pertains to prediction of effective horizontal sound speeds in long-range underwater sound propagation. The Adiabatic Invariant Approximation method is used for comparison with known travel time between Australia and Bermuda. The work was done under the NOSC contract with the Air Force Technical Applications Center, Patrick Air Force Base, Florida, under the 1035 TCHOG Project Authorization T/0158/0/NOSC. Capt NE Lowell was the contract officer.

Released by
NO Booth, Head
Environmental Acoustics Division

Under authority of
JD Hightower, Head
Environmental Sciences Department

ACKNOWLEDGEMENTS

JG Colborn of NOSC assisted in the computing and in NODC data retrieval. Carl Hartdegen, of the Palisades Geophysical Institute SOFAR station, Bermuda, supplied the shot and travel time data.

(14) NOSC/TR-621

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NOSC Technical Report 621 (TR 621)	2. GOVT ACCESSION NO. AD A094154	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) VERIFICATION OF THE ADIABATIC INVARIANT APPROXIMATION FOR COMPUTING EFFECTIVE HORIZONTAL SOUND SPEEDS IN A RANGE-DEPENDENT ENVIRONMENT.		5. TYPE OF REPORT & PERIOD COVERED (9) Interim report. April-September 1980,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J Northrop RC Shockley PG Hansen		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Systems Center San Diego, CA 92152		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS T/0158/0/NOSC
11. CONTROLLING OFFICE NAME AND ADDRESS USAF Tactical Applications Center Patrick AFB, Florida		12. REPORT DATE (11) September 1980
		13. NUMBER OF PAGES 18 (12) 21
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Explosive sound source Underwater sound propagation Ray tracing Adiabatic invariant		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Use of the Adiabatic Invariant Approximation (AIA) for determining horizontal sound speeds in a range-dependent environment has been proposed recently [R. C. Shockley, J. Acoust. Soc. Am. 64, 1171 (1978)]. Because the method provides a great saving in computer time over conventional ray-tracing techniques, it was applied to two very-long-range paths, from Perth, Australia, to Bermuda and to Fernando de Noronha (19763.0 and 14549.3 km, respectively), where measured travel times are available. Results show that the AIA method predicts effective horizontal sound speeds of 1482.3 m/s and 1480.4 m/s, respectively, for the two propagation paths. These results compare favorably with the measured values of 1484.7 ± 3.7 m/s and 1480.1 ± 0.9 m/s.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

393159

JCC

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

The problem of tracing rays along a propagation path with range-dependent sound-speed profiles (SSPs) has confronted workers in the field of underwater acoustics for many years. Not only are conventional ray-tracing techniques expensive in terms of computer time, but also such ray tracing is redundant for many applications because ray trajectories are cyclic within a given SSP zone. In addition, when the ray reaches a boundary between two adjacent SSP zones, one must decide how to trace the ray across the boundary. This is a difficulty because Snell's law does not apply in range-dependent environments. These problems are minimized in the Adiabatic Invariant Approximation (AIA) method, which assumes that the phase integral, J, is constant along the entire track.[1] One only has to compute J for several arrays in each adjoining zone to determine which sound speed is appropriate there, because a discrete sound speed is associated with each value of J.[2] Thus, only the value of J for the appropriate ray angle and the associated horizontal sound speeds over the length of the SSP zones are required in order to calculate the effective horizontal sound speed (EHSS). As a test of this method, travel times for sound signals from depth charges fired from the R/V VEMA and HMAS DIAMANTINA

---

[1] DE Weston, "Guided Propagation in a Slowly Varying Medium," Proc. Phys. Soc. London, 73, 365-384 (1959).

[2] RC Shockley, "Paraxial and Nonparaxial Ray Speeds in Strongly Range-Dependent SOFAR Channels" J. Acoust. Soc. Am., 64, 1171-1177 (1978).

off Perth, Australia, and received at Bermuda and Fernando de Noronha were obtained[3,4] and sound speeds computed for comparison with those predicted by the AIA.

METHOD

The great circle paths between the shot positions and hydrophones were calculated on a computer. The computed paths were then overlaid on a bathymetric chart of the world (Fig 1). Bottom depths and typical SSPs were selected at various intervals along these paths and used for input to the RAYWAVE program[5] for obtaining the arrival angle of rays at the hydrophone. The SSPs were also used for computing the value of adiabatic invariant, J, for the AIA sound-speed determinations. A weighted average of these sound speeds, one for each SSP regime, was calculated for the EHSS over the great circle paths. The sound speeds and ranges are shown in Table 1.

SOUND-SPEED PROFILES

Archived SSPs were culled from the NODC (National Ocean Data Center) files for the South Indian, Southeast Atlantic, and North Atlantic oceans. Nine of these, which were in the proximity of the propagation path for the season when

---

[3] "Notes and Personalia," Trans. Am. Geophys. Union, 41, 670 (1960), submitted by C Hartdegen.

[4] Personal Communication, C Hartdegen, Palisades SOFAR Station, FPO NY 09560.

[5] Naval Undersea Center, "Raywave II: A Propagation Loss Model for the Analysis of Complex Ocean Environments," NUC Technical Note 1516, by WH Watson and R McGirr, 1975

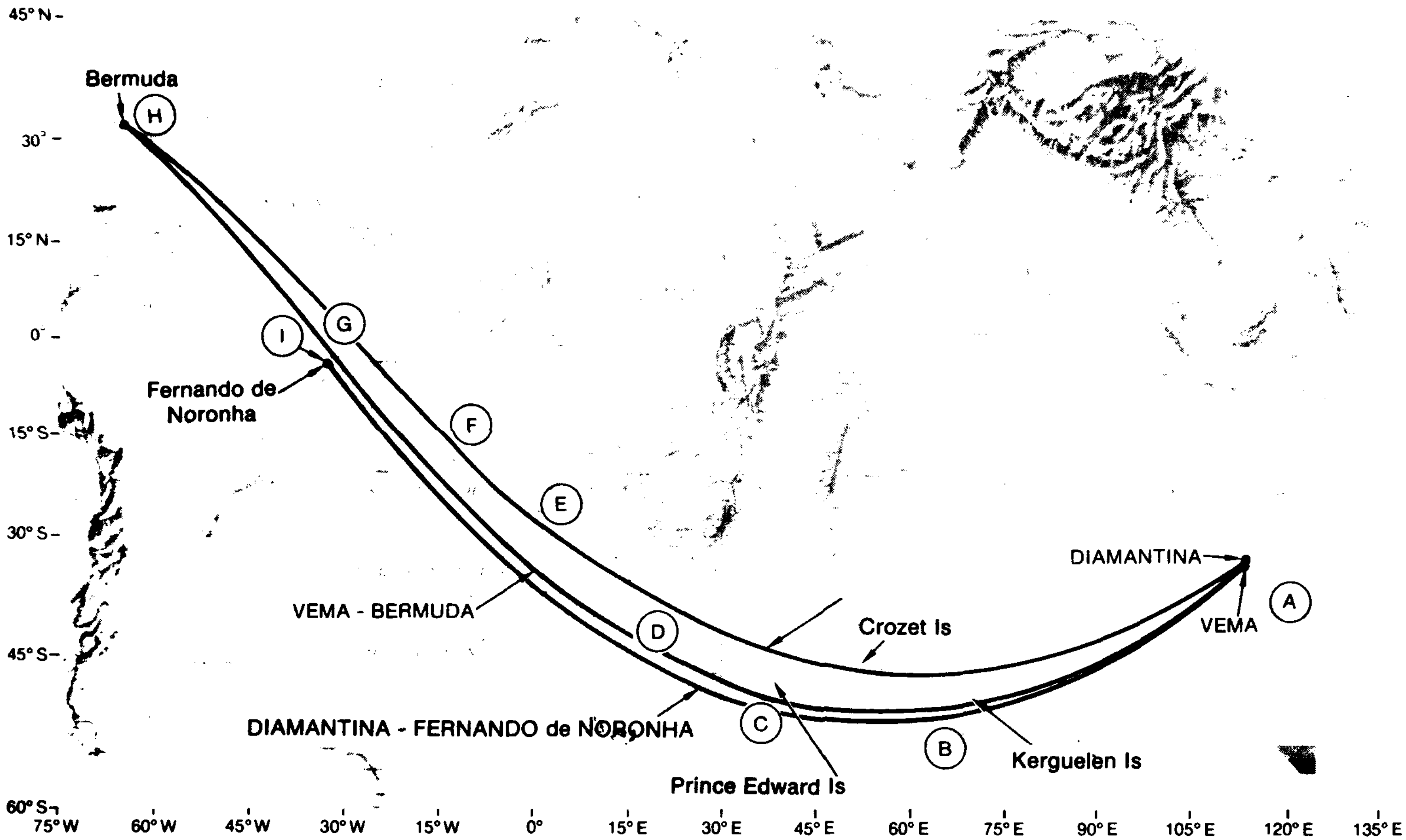

Figure 1. Bathymetric chart (NOO 1262 A) showing the great circle propagation paths from Australia to Bermuda and Fernando de Noronha. Locations of selected sound-speed profiles are shown by alphabetical notation.

Table 1. Shot and receiver positions, ranges, travel times, and measured and computed effective horizontal sound speeds.

Hydrophone Position LAT.	Hydrophone Position LONG	Shot Position LAT.	Shot Position LONG.	Great Circle Distance, km	Travel Time, h, min, s	Sound Speed, m/s Measured	Sound Speed, m/s Computed RAYWAVE	Sound Speed, m/s Computed AIA
		(VEMA)*						
32°11'N	64°36'W	33°36.3'S	113°29.0'E	19763.0	3:41:18 to 3:42:24	1484.7±3.7	1477.2±0.4	1482.3±1.1
		(DIAMANTINA)**						
32°11'N	64°36'W	33°13'S	113°43'E	19806.7	3:42:44 to 3:42:55	1481.4±0.6	1478.0±.8	1482.3±1.1
3°56'S	32°23'W	33°13'S	113°43'E	14549.3	2:43:43‡ to 2:43:54	1480.1±0.9	1473.4±1.2	1480.4±0.9

* Six shots of 200 lb TNT each.
** Three shots of 300 lb Amatol each.
‡ The station records 3 h, 44 min, 43 s, but timing is believed 1 min off.

the field work was done, were selected as representative of the SSP provinces along the path. The locations of the selected profiles, A through I, are shown in Fig 1 and the profiles themselves in Fig 2. The latitude, longitude, and date of the profiles are listed in Table 2.

Profile A, which is typical of those in southern waters off Australia, has a surface sound speed of 1507.0 m/s, a shallow surface duct, and a deep (1200 m) sound-speed minimum. The next two profiles (B and C of Fig 1 and 2) lie south of the Antarctic Convergence, have very low surface sound speeds (near 1460 m/s), a very shallow surface duct, and a sharp sound-speed minimum at a depth of 250 m. Profile D, south of the Cape of Good Hope, is north of the Antarctic Convergence, has a broad sound channel with the axis near 900 m, and a shallow surface duct. Profile E, near the Walvis Ridge, has a much higher surface sound speed (1525 m/s), a very shallow surface duct, and sharp negative gradient that persists down to the sound-speed minimum at 700 m. Profile F is on the Mid-Atlantic Ridge near Ascension Island. It has a high surface sound speed near 1535 m/s, a shallow surface duct, and a sharp negative gradient down to the SOFAR axis at 900 m. Profile G, on the Mid-Atlantic Ridge just north of the Equator, has a surface sound speed of 1541 m/s, a sharp negative gradient, and a broad minimum near 900 m. Profile H, near Bermuda, has a relatively deep surface layer (375 m), and a deep (1100 m) sound-speed minimum of 1491 m/s. Profile I, at Fernando de Noronha, has a surface sound speed of 1543 m/s, a 30-m surface duct, and an axial sound speed of 1481.2 m/s. These profiles clearly exhibit distinct characteristics pertaining to their separate hydrologic regimes. Some support continuously refracted (RRR) transmission, and others (profiles B and C) support refracted/surface reflected (RSR) ray paths. Because the deep sound channel is present at both the Australian and Bermudian ends of the propagation paths, but not in the middle,

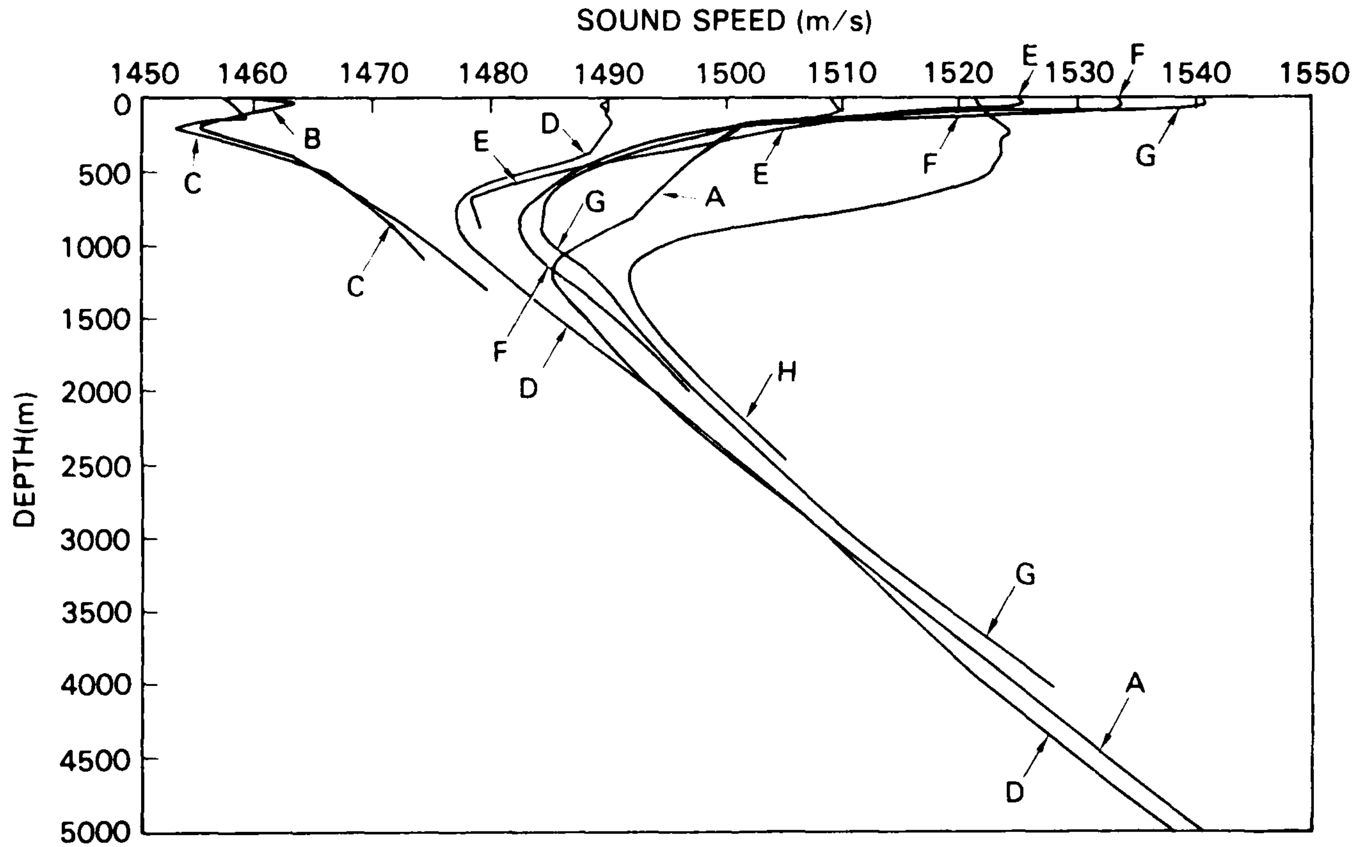

Figure 2. Sound-speed profiles A-I used in the computations. Locations of profiles are keyed to the map, Fig 1.

Table 2. Positions and dates of the sound-speed profiles used in the AIA and RAYWAVE programs.

PROFILE	LATITUDE	LONGITUDE	MONTH	DAY	YEAR
A	40°05'S	120°07'E	MAR	5	1960
B	54°0'S	63°13'E	FEB	4	1969
C	51°55'S	35°42'E	MAR	4	1963
D	43°18'S	16°02'E	NOV	9	1957
E	26°03'S	8°01'E	APR	4	1961
F	11°30'S	11°56'W	SEP	21	1963
G	5°59'N	30°06'W	MAR	6	1963
H	32°19'N	64°12'W	FEB	13	1959
I*	3°30'S	32°38'W	MAR	22	1963

*This profile used for computing the Fernando de Noronha data.

ray paths change from RRR to RSR at the Antarctic Convergence and then back to RRR again. The deep sound channel thus narrows and shoals, then becomes broad and deep. Clearly, ray tracing through such complicated and diverse SSP regimes is a challenge to any program and presents a good test for the AIA method.

BATHYMETRY

The source area is over the deep Continental Rise off Perth, Australia. Propagation was initially across the basin west of Perth, then across the southeast Indian Ridge, the Kerguelen-Gaussberg Ridge, the East Crozet Basin, and the shoals around Crozet and the Prince Edward Islands before entering the South Atlantic's Agulhas Basin. From there the path crossed the Cape Rise, the Walvis Ridge, the Mid-Atlantic Ridge (twice), and the North American Basin before reaching the SOFAR hydrophones on the Bermuda Pedestal at 1322 m depth. The path to Fernando de Noronha is similar but crosses the Mid-Atlantic Ridge only once before reaching the hydrophones at 824 m depth.

In order to simplify the task of reading bottom depths along such a complicated path, 50 contour crossings were picked from the chart (Fig 1) and their ranges from the hydrophones tabulated. This information was used for input to the RAYWAVE[5] program for computing propagation loss and arrival-angle information.

COMPUTING THE ADIABATIC INVARIANT

The adiabatic invariant, J, was computed for each of the SSP regions thus:

$$J = \oint c^{-1} \sin\theta \, dz \qquad (1)$$

where c is the local depth-dependent sound speed, θ is the ray angle with the horizontal, and z is the depth coordinate. The integration is over one ray cycle and, in the RAY 2 program used,[6] four cycles were computed for redundancy. The program smooths each SSP by means of a cubic spline fit before integration.

Values of J were computed in this manner for angles of from 0.5 to 20 deg in 0.5 -deg intervals for each of the SSPs. These values, shown in Fig 3, indicate the range of J for the range of angles selected for the SSPs. Any sharp discontinuity in these curves indicates that either there was an error in the SSP data, or that the ray path type has changed (eg, from surface duct to refracted-surface-reflected).

COMPUTING AVERAGE RAY SPEED

The average ray speed, $\bar{c}$, was calculated for each of the eight SSPs for various values of J by the computer program RAY 2.[6] As shown in Fig 4, some of these curves have a peak at relatively low values of J. This initial peak

---

[6] Naval Ocean Systems Center, "Phase Integral Algorithms for Signal Speeds in Range-Dependent Sound Velocity Profiles," NOSC Technical Report 412, by RC Shockley, 1978.

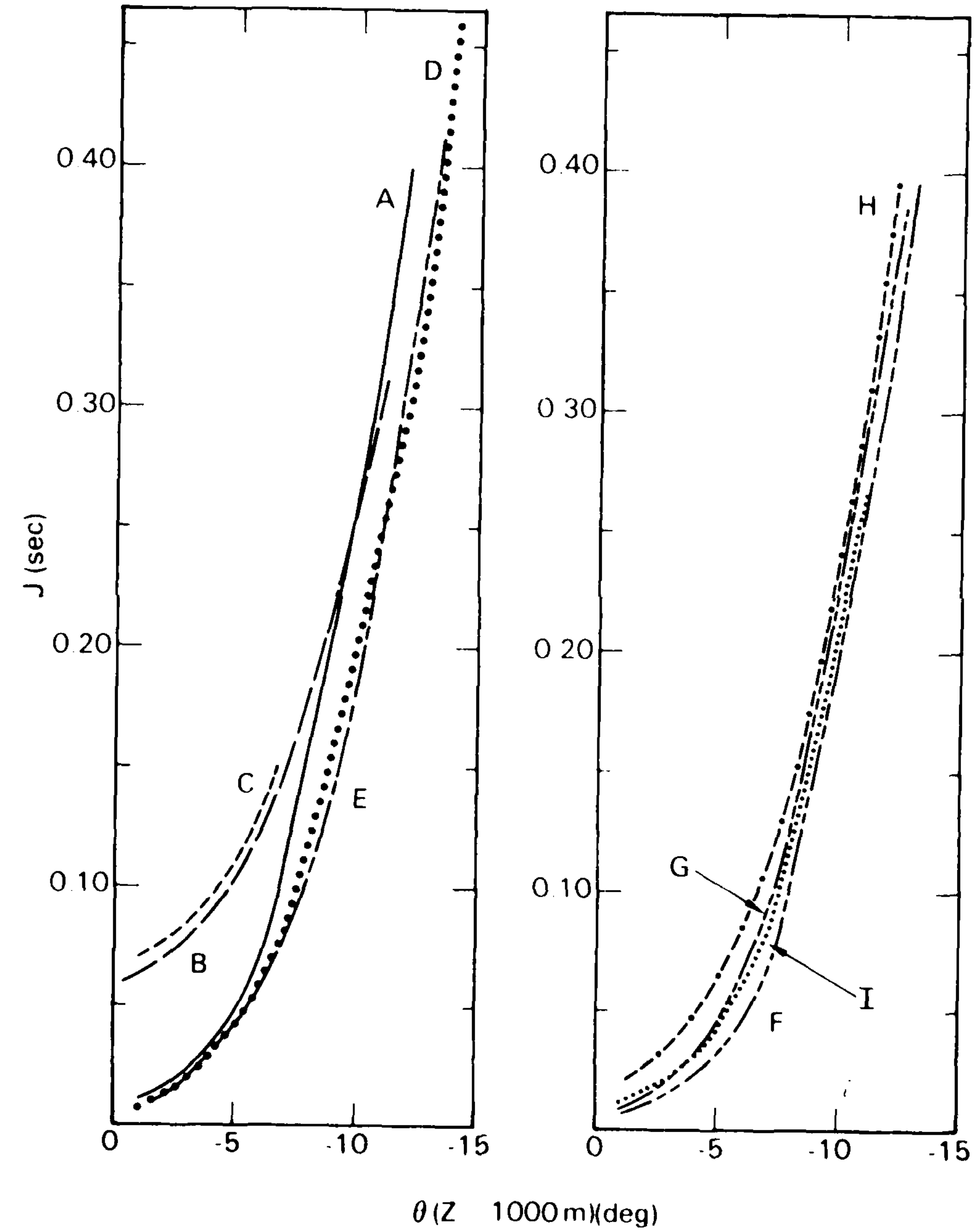

Figure 3. Plot of J values versus ray angle (θ) with the horizontal for the SSPs for a source depth of 1000 m. Identification of curves is keyed alphabetically with those of Fig 2.

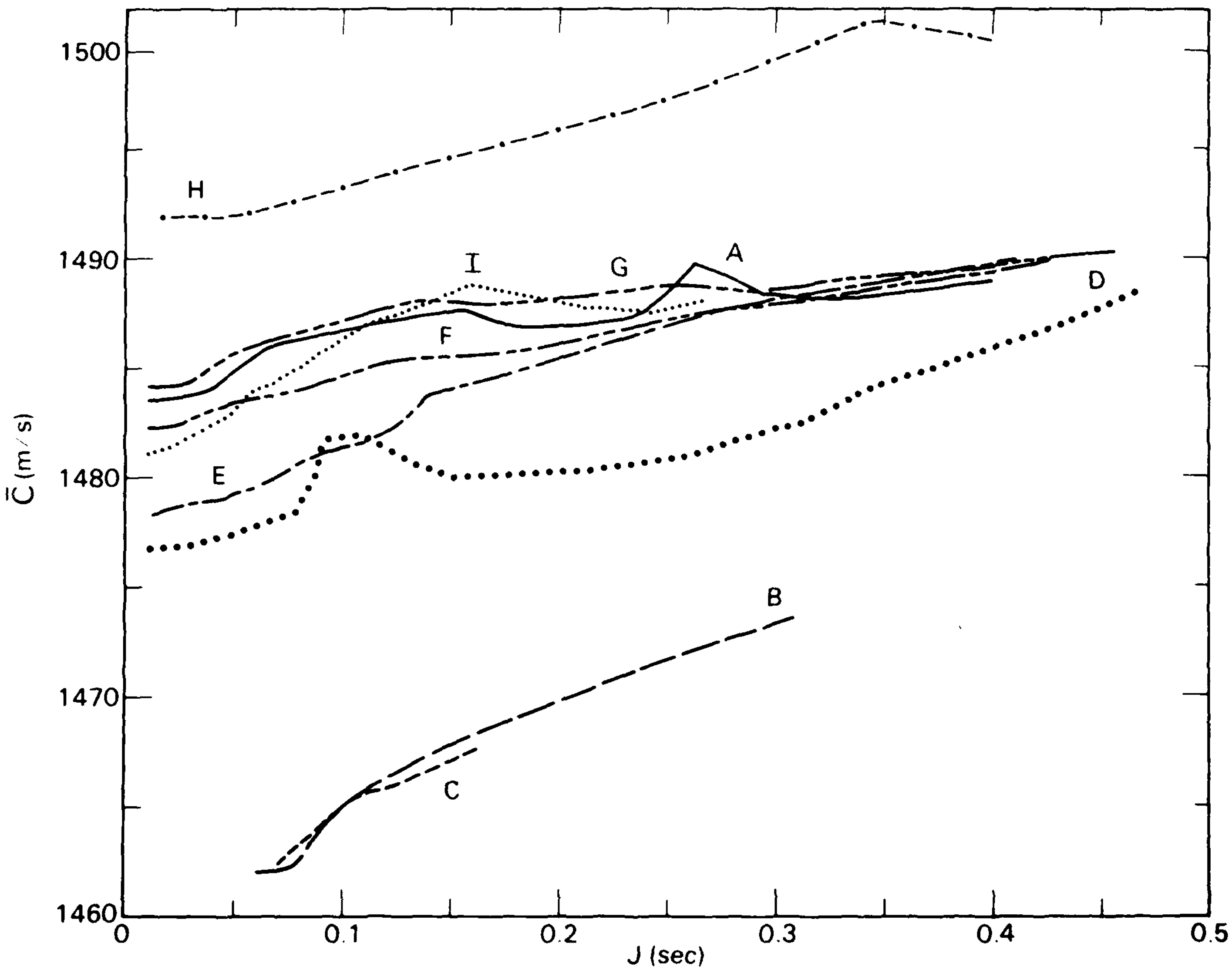

Figure 4. Plot of average horizontal ray speeds versus J for each of the SSPs. Identification of curves is keyed alphabetically with those of Fig 3. Bottom reflection causes termination of some curves for steeper rays (higher J values).

separates the regions where continuously refracted propagation takes place (to the left of the peak) from the RSR region. For example, the points for profile C, south of the Antarctic Convergence, are all to the right of the peak, indicating that propagation is entirely in the RSR mode, as could be surmised by inspection of the SSPs (Fig 2). Curve H exhibits no peak for the values of J plotted, indicating that RRR propagation prevails. Since this is the profile for Bermuda and has a sharp thermocline and pronounced SOFAR channel (curve H of Fig 3), this is a correct interpretation. The other curves of Fig 4 are intermediate between these two types and indicate hydrologic regimes that support both RSR and RRR propagation for different J values.

COMPUTING EHSS

EHSS, the speed of signal propagation between widely separated sources and receivers, is calculated as the weighted average of ray speeds in each SSP zone according to the following relationship:[6]

$$\overline{c} = \text{EHSS} = R/\sum_i \left(R_i/\overline{c}_i\right) \qquad (2)$$

where R denotes the total range, R_i the distance traveled in region i, and $\overline{c}_i$ the average horizontal ray speed for the pertinent eigenray in the region. In this report, the fraction of the time spent in each region is assumed to be half the zone width. For example, the time spent in SSP region C was taken as the sum of half of the range between B and C and half that between C and D. For the terminal segments of the paths (A-B, G-H), the ratios were 2/3 and 1/3, the 2/3 being at the end. The rays carrying the principal amount of energy were the 5.5 -deg ray at Bermuda (Fig 5) and the 6.5 -deg ray at Fernando de Noronha (Fig 6). For the weighted average, the ray speeds corresponding to J values for these angles were read from the curves of Fig 4.

RESULTS

By means of the Adiabatic Invariant Method, the calculated EHSS between a shot point at 1000 m near Perth, Australia, and SOFAR hydrophones near Bermuda was 1482.3 m/s. This compares favorably with the measured values, which ranged from 1481.0 m/s to 1488.4 m/s for the six 200-lb shots fired from VEMA and 1480.8 m/s to 1482.0 m/s for the three 300-lb shots from DIAMANTINA. For the later shots, an independent calculation using RAYWAVE[7] gave a sound speed of 1478.0 ± 0.8 m/s.

For the path to Fernando de Noronha, the AIA method gave an EHSS of 1480.4 m/s, which compares favorably with the field measurement of 1480.1 ± 0.9 m/s. An independent calculation using RAYWAVE[7] gave a sound speed of 1473.4 ± 1.2 m/s.

---

[7] Naval Ocean Systems Center, "Underwater Sound Propagation between Perth, Australia, and Bermuda: Theory and Experiment," NOSC Technical Report 585, by J Northrop and C Hartdegen, 1980.

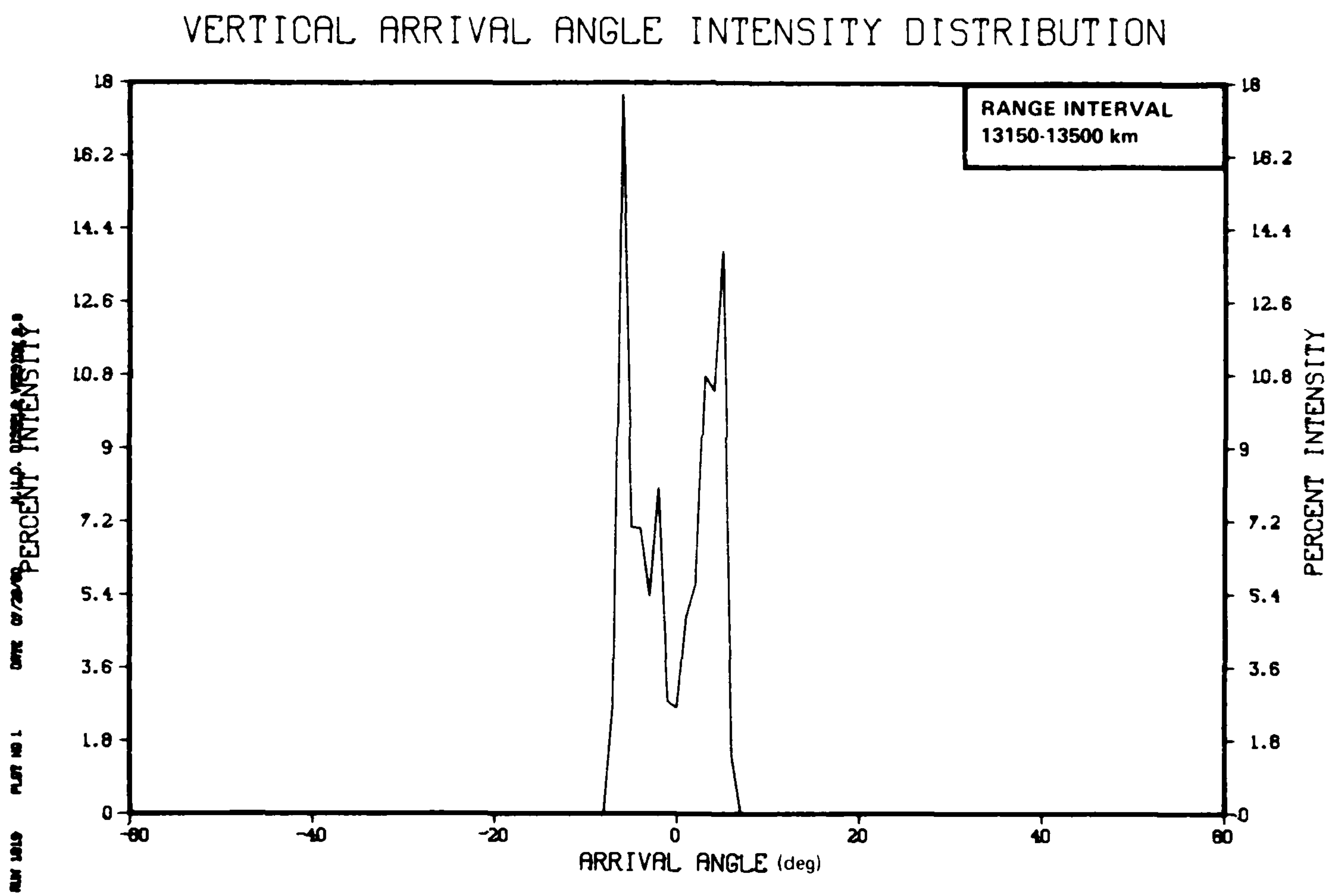

Figure 5. Plot of the percent intensity of sound at Bermuda versus ray angle for the propagation path to Australia.

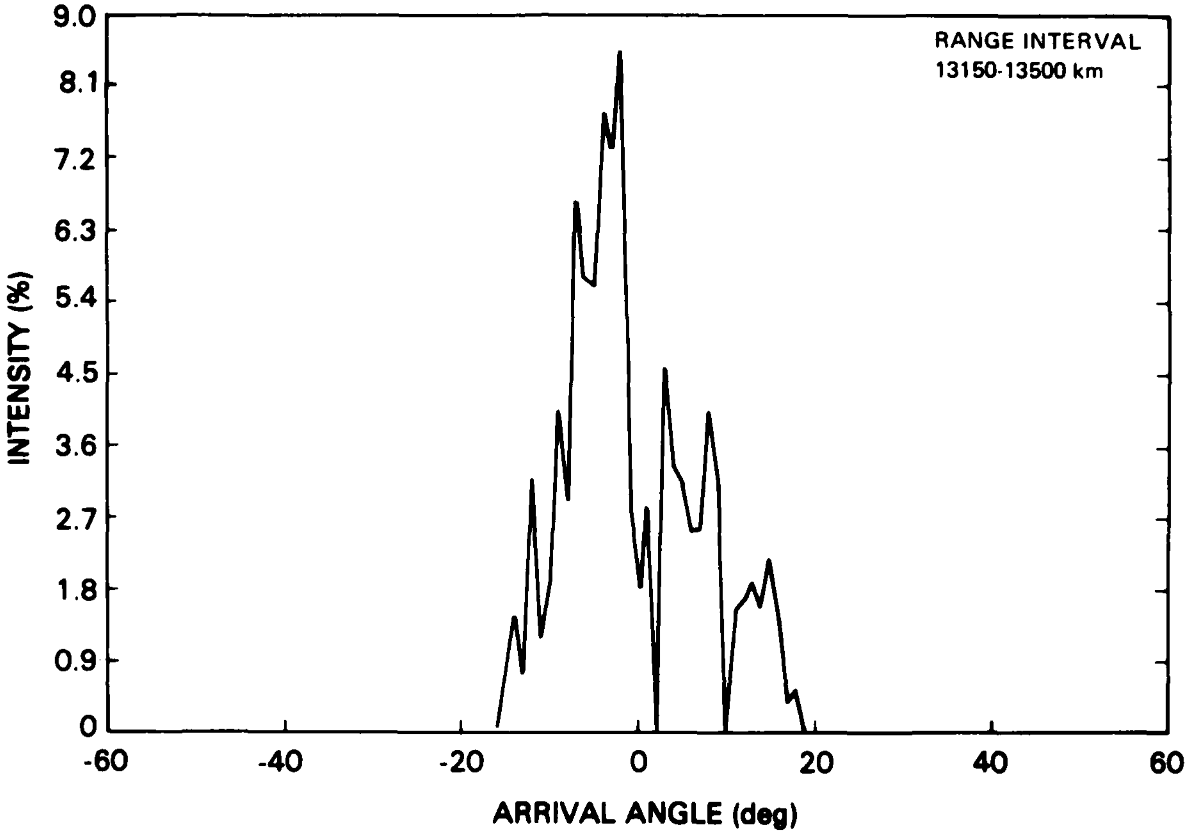

Figure 6. Plot of the percent intensity of sound at Fernando de Noronha versus ray angle for the propagation path to Australia.

CONCLUSIONS AND RECOMMENDATIONS

The AIA method of computing EHSS in a range-dependent environment is practical, accurate and, in terms of computer costs, an order of magnitude cheaper than RAYWAVE. For a travel path almost halfway around the world (Australia to Bermuda), the AIA method predicts an EHSS that is very close (within a few meters per second) to the measured value and at a fraction of the cost of conventional ray-tracing techniques. It is recommended that additional AIA predictions be made for other propagation paths where shot data are available.

REFERENCES

1. DE Weston, "Guided Propagation in a Slowly Varying Medium," Proc. Phys. Soc. London, 73, 365-384 (1959).

2. RC Shockley, "Paraxial and Nonparaxial Ray Speeds in Strongly Range-Dependent SOFAR Channels" J. Acoust. Soc. Am., 64, 1171-1177 (1978).

3. "Notes and Personalia," Trans. Am. Geophys. Union, 41, 670 (1960), submitted by C Hartdegen.

4. Personal Communication, C Hartdegen, Palisades SOFAR Station, FPO NY 09560.

5. Naval Undersea Center, "Raywave II: A Propagation Loss Model for the Analysis of Complex Ocean Environments," NUC Technical Note 1516, by WH Watson and R McGirr, 1975.

6. Naval Ocean Systems Center, "Phase Integral Algorithms for Signal Speeds in Range-Dependent Sound Velocity Profiles," NOSC Technical Report 412, by RC Shockley, 1978.

7. Naval Ocean Systems Center, "Underwater Sound Propagation between Perth, Australia, and Bermuda: Theory and Experiment," NOSC Technical Report 585, by J Northrop and C Hartdegen, 1980.